DSMS Level-1 Requirements

Purpose: This document specifies the Level-1 Requirements on the DSMS Program, the result of negotiations between NASA Code S and the Interplanetary Network Directorate, of the Jet Propulsion Laboratory. These requirements and strategies to fulfill them will form the basis for future funding agreements between the DSMS Program and NASA Code S. All references enhancements or improvements below are relative to the DSMS capability in 2005.

Requirements

1. DSMS shall evolve its capabilities on the schedule shown in the table below to meet the needs of the ambitious flight mission scenarios described in the appendix. The column for 2005 is the current baseline capability. The remaining three columns (2010, 2020, and 2030) represent views of the evolving architecture and its capabilities. All metrics are referenced to future missions or mission classes according to the footnotes.

Capability	***2005***	***2010***	***2020***	***2030***
Communications				
Supported frequencies bands	S/X/Ka	S/X/Ka	X/Ka/Optical	X/Ka/Optical
Downlink				
Number of simultaneous links[C]	15[A]	12[A]	27[B]	32[C]
Required data rate capability from Mars (Mbps)	2.5[D]	14[E]	150[F]	3,750[G]
Required throughput for highest data rate user (Mbps)	2.5[D]	14[E]	150[F]	1,500[H]
Uplink				
Number of simultaneous links	15[A]	12[A]	21[I]	22[I]
Required data rate capability to Mars (Mbps)	0.004[J]	0.016[K]	0.072[L]	20[M]
Required throughput for highest data rate user (Mbps)	0.004[J]	0.016[K]	1.5[N]	20[M]
Navigation				
Orbit control accuracy on approach, Mars & terrestrial bodies (km)	2[O]	2[P]	1[Q]	0.5[R]
Orbit Control Accuracy on approach, Outer Planets (km)	20[S]	20[S]	2[T]	10[U]
Orbit control accuracy, in orbit (km)	5[V]	5[V]	1[Q]	<1[R]
Orbit reconstruction accuracy, in orbit (km)	0.010[W]	0.010[V]	0.001 radial[T]	< 0.001 radial[R]
Landing accuracy on surface (km)	21x5[O]	5x5[P]	0.025x0.025[X]	0.1x0.1[R]
Position determination of landed vehicle (km)	0.020[O]	0.001[P]	0.001[Q]	0.001[R]
***In-situ* Support Asset Locations**	Mars	Mars, Moon	Mars, Moon, others (TBD)	Mars, Moon, others (TBD)

2. DSMS shall provide multi-mission services for telecommunications and navigation to support NASA and NASA approved missions to targets throughout and beyond the Solar System at the levels of performance indicated by Requirement 1 with the following attributes:

- DSMS shall be capable of providing two-way communications between Earth and a deep space spacecraft (uplink and downlink) any time a spacecraft is unobstructed along the line-of-sight from the Earth;
- DSMS shall provide measurements to users that enable and enhance flight navigation and surface positioning of spacecraft;
- DSMS shall provide multi-mission communications and navigation infrastructure for *in situ* activities at Mars as well as at other specified targets in the Solar System;
- DSMS shall provide these capabilities at required performance levels for all mission phases, including: launch and early orbit phase; initial acquisition; normal flight operations; emergency operations, and critical events;
- DSMS shall be capable of measuring the quality of all negotiated services that use only DSMS-controlled systems
- DSMS shall provide these capabilities with reliability = 95% (i.e. the probability of failing to achieve a negotiated service will be less than 5%)
- During especially critical events (e.g. orbit insertion, entry-descent-and-landing, trajectory correction maneuvers, and encounters) DSMS will bring to bear all available and appropriate physical and human resources to maximize the probability of achieving = 99% successful uplink, downlink, tracking, and navigation.

3. DSMS shall provide its users with standard and accountable interfaces to obtain these services (including scheduling), whether in design, development, test or operations.

4. DSMS shall work with current and future users to develop advanced services and tools that enhance capability (according to the table) and lower cost (TBD).

5. DSMS shall support NASA and JPL public outreach and educational partnerships.

[A] Current capability with 5 antennas (uplink and downlink) at Goldstone, 3 antennas at Canberra, and 4 antennas at Madrid. 2005 capability includes the 26m subnet (3 links)
[B] Based on the number of missions in the 2020 Mission Scenario
[C] Based on the number of missions in the 2030 Mission Scenario
[D] Mars Reconnaissance Orbiter data rate capability
[E] Mars Telecommunications Orbiter data rate capability
[F] Based on next generation Mars telecommunications orbiter described in 2020 mission scenario
[G] Titan Explorer data rate capability "normalized" to Mars
[H] Third generation Mars telecommunications orbiter described in the 2030 mission scenario
[I] Based on the number of required downlinks in 2020[D] and 2030[C] and the assumption that missions require a ratio of uplink/downlink of 2/3.
[J] Current command data rate capability of the standard spacecraft transponders
[K] Planned uplink capability based on 2010 mission scenario, uplink data rate is spacecraft hardware limited, JWST at 16 kbps.
[L] Based on a possible Europa Lander emergency command (8 bps, LGA), in the 2020 mission scenario, normalized for an HGA (30 dB gain) at Mars
[M] Based on human mission to Mars in 2030 mission scenario
[N] Based on human mission to the Moon in 2020 mission scenario
[O] Mars Exploration Rovers
[P] Required for Mars Science Laboratory (MSL)
[Q] Required for Mars Sample Return (MSR)
[R] Required for advanced MSL, advanced MSR, & Human Exploration
[S] Required for Cassini
[T] Required for Jupiter Icy Moons Orbiter (JIMO)
[U] Required for Cassini follow on
[V] Required for Mars Reconnaissance Orbiter
[W] Mars Global Surveyor capability
[X] Required for Comet Sample Return

Requirements:

1. **Space Link Extension** Project Operation Control Centers (POCCs) using DSN and SN services should utilize a standard *Space Link Extension* (SLE) *Services Interface* for transferring data to and from DSN or SN sites.
    a. This interface is designed to provide international control center–network interoperability and reduce mission risk by facilitating the rapid substitution of a different earth station, not necessarily only NASA's, in the event of a failure.
    b. In 2005 and beyond, the SLE Services interface will require POCCs to directly access DSN stations for the following services:
        i. Command Link Transmission Unit (CLTU),
        ii. Return All Frames (RAF),
        iii. Return Channel Frames (RCF), and
        iv. CCSDS File Delivery Protocol (CFDP).

Proposers interested in SN or GN services should contact the person named in Section 1.3.2.2. in the New Frontiers Proposers Guide.

Seven international space agencies, including: ASI, CNES, DLR, ESA, ISAS, NASA, and NASDA, have agreed to implement the SLE Services Interface to achieve full international interoperability.

Interface architecture conforms to standards adopted by the CCSDS. It has been operational in the DSMS since October 2002 and missions launching after that date should plan to use this system.

2. **X-Band and KA-Band Communications (DSN, GN, SN)**
    a. Category B ($r = 2 \times 10^{6}$ km) missions operating in a *Space Research* allocation launching after
        i. 2002 should be designed to communicate in either the 7/8 GHz or 7/32 GHz bands.
        ii. Ever increasing congestion and the addition of allocations for incompatible services have restricted future operations in the 2 GHz deep space band. Accordingly, the Science Mission Directorate recommends that use of the 2 GHz deep space band be limited to radio
        iii. science and in-situ communications.
        iv. Deep space missions having high data rates should operate in KA-Band (31.8 - 32.3 GHz space-to-earth) or, if using the 8400-8450 MHz band, they should comply with SFCG Recommendations regarding bandwidth-efficient modulation. Approved methods for bandwidth efficient modulation can be found in Reference 3. [in the New Frontiers Proposers Guide.]

    b. Category A ($r < 2 \times 10^{6}$ km) missions also have an allocation for the *Space Research* service in the 7190 - 7235 MHz (Earth-to-space) and 8450 - 8500 MHz (space-to-Earth) bands.

i. Because of the congestion in the 2 GHz band from ever increasing use, proposers are encouraged to use the 7/8 GHz bands whenever possible.
ii. Missions operating in either the 2 or 7/8 GHz bands should comply with the spectrum emissions mask in the SFCG Handbook.
iii. Approved methods for bandwidth efficient modulation can be found in Reference 3. [in the New Frontiers Proposers Guide.]
iv. Category A Missions with high data/symbol rates planning to operate in the 8 GHz *Earth Exploration Satellite* (EES) (8025 - 8400 MHz) should investigate capabilities in the 26 GHz band. Missions utilizing the EES service tend to have very high data/symbol rates and all missions planning to operate in the 8 GHz band should comply with the spectrum emissions mask in the SFCG Handbook.
v. Approved methods for bandwidth efficient modulation can be found in Reference 3. [in the New Frontiers Proposers Guide.]
vi. Additionally, a new allocation for the *Space Research* service is being requested in the 25.5 - 27.0 GHz band (a.k.a. 26 GHz band) at the World Radio Conference (WRC) in 2003. If this new allocation is adopted at WRC 03, high data rate space science missions, requiring bandwidths in excess of 10 MHz, should be designed to operate in the 26 GHz band.

3. Bandwidth Efficient Modulation (DSN, GN, SN)

a. Missions operating in the 2 and 8 GHz bands, should employ bandwidth efficient modulation methods in conformance with SFCG and CCSDS Recommendations.
b. Spectral Emission Masks for Category A missions are found in the Space Frequency Coordination Group's (SFCG's) Handbook, available on the SFCG web site.
c. Specific modulation methods meeting the SFCG mask are enumerated in CCSDS Recommendations 401 (2.4.17A) B-1, and 401 (2.4.18) B-1 for non-deep space and Earth resources missions, respectively.
d. As a matter of IND policy, it is recommended that Category B missions employ bandwidth efficient modulation whenever operating in the 8400 - 8450 MHz band at symbol rates above 2 Msps. CCSDS Recommendation 401 (2.4.17B) B-1 lists acceptable modulation schemes.

4. CCSDS File Delivery Protocol (DSN, GN, SN)

a. To improve station utilization efficiency as well as reduce **mission risk and costs**, all DSN users should employ the CCSDS File Delivery Protocol (CFDP), to transfer data to and from a spacecraft.
b. CFDP operates over a CCSDS conventional packet telecommand, packet telemetry, or an Advanced Orbiting System (AOS) Path service link. CFDP enables the automatic transfer of a complete set of specified files and associated information from one storage location to another replacing an expensive labor-intensive manual method.
c. It can transfer a file from a source point to a destination site using an Automatic Repeat Queuing (ARQ) protocol.
d. In an *acknowledged mode*, the receiver notifies the transmitter of any undelivered file segments or ancillary data so that the missing elements can be retransmitted guaranteeing delivery. An *unacknowledged mode* is also permitted. CFDP information can be found in

the *CCSDS File Delivery Protocol* Blue Book available under the *Advanced Orbiting Systems* category on the CCSDS web site

5. **Multiple Spacecraft Per Antenna (DSN)**
   a. Where a multiplicity of spacecraft lie within the beamwidth of a single DSN antenna, it may be possible to capture data from two or more spacecraft simultaneously using the Multiple Spacecraft Per Aperture (MSPA) system.
   b. **MSPA decreases DSN loading and will save the project's money**.
   c. There are a few constraints. First, only a single uplink frequency can be transmitted. Generally, this means that only one spacecraft at a time can operate in a two-way coherent mode, while the remainder must be in a one-way (i.e., non-coherent) mode.
      i. Second, multiple independent receivers are required at the Earth station. This sets a practical limit on the number of spacecraft that can be served simultaneously.
      ii. Third, ranging and two-way coherent Doppler data can only be obtained from the single spacecraft operating in a two-way coherent mode.
   d. Approximately 30-minutes are required to transfer two-way coherent operations from one spacecraft to another irrespective of whether or not the spacecraft, which will be in the two way coherent mode, is currently part of the MSPA cluster.
   e. When switching the uplink from one spacecraft to the next, full *Aperture Fee (AF)* costs apply to the new two-way coherent user at the onset of the switching operation.
   f. Transfers of two-way coherent operations requires:
      i. Tuning the uplink of the spacecraft in a two-way coherent mode to its rest frequency,
      ii. Setting the station uplink frequency to the next spacecraft's and acquiring the uplink,
      iii. Reconfiguring the command subsystem (if required) for the next spacecraft,
      iv. Reconfiguring ranging (if required) for the next spacecraft,
      v. Reconfiguring the Monitor and Control subsystem,
      vi. Relocking the Earth station's receiver and telemetry processor following the switch.
   g. For a Project to avail itself of the MSPA savings, the following conditions must apply:
      i. All spacecraft must lie within the beamwidth of the requested antenna.
         a) Projects must accept reduced link performance from imperfect pointing.
      ii. Spacecraft downlinks must operate on different frequencies.
   h. Only one spacecraft at a time can operate with an uplink in a coherent mode.
      i. Commands can only be sent to the spacecraft receiving an uplink.
      ii. Ranging & coherent Doppler are available from the spacecraft in a 2-way mode.
      iii. Remaining spacecraft transmit 1-way downlinks with telemetry only.

6. **Delta Differenced One-Way Range (DSN)**
   a. DDOR is VLBI navigation to measure the precise position in the plane of the sky. Coupled with Ranging, navigators get a three dimensional position of the s/c
   b. DDOR can be used in conjunction with Ranging and Doppler data to:
      i. Increase spacecraft targeting accuracy (when used with range and Doppler data).
      ii. Improve the probability of mission success when used with range and Doppler data.

    iii. Reduce tracking time if pass duration is driven by tracking data capture.
c. Projects should investigate whether this data type offers sufficient improvement in one or more of the above parameters to justify the cost in terms of spacecraft implementation, operational complexity, and Earth station scheduling.
d. Under the proper conditions, DDOR can offer significant benefits including a reduced mission cost.
e. For (DDOR) to be usable:
    i. The spacecraft must transmit two tones (the greater the frequency separation the better).
    ii. Two DSN Earth stations must observe the spacecraft and natural radio sources.

7. Relayed Data (DSN)

a. Some missions may propose dropping probes, landers, or even rovers to explore the surface of a planet.
b. Others may insert orbiters around the same body.
c. The result can be a multiplicity of spacecraft on or around a planet. While Mars has been the recent focus, it is foreseeable that other planets or objects in space could be of equal interest in the future.
d. Where several spacecraft are relatively close together and positioned far from the Earth, it makes sense to send data to and from small vehicles via a relay (Proximity Link).
e. Typically, this has been an orbiting spacecraft carrying a special transceiver operating at UHF frequencies.
f. Relaying data from surface objects can save money and reduce size and power requirements of landed equipment.
g. Proposals for landed objects in the vicinity of an orbiting spacecraft should consider whether a data relay makes sense for their application.
h. Some *Announcements of Opportunity* (AOs) have required orbiting spacecraft with certain characteristics to carry Proximity Link hardware.
i. A specific relay link design [Proximity Link] has been adopted by the CCSDS.

8. Coding

Most missions employ error detecting – error correcting codes to substantially improve telemetry link performance. DSMS users are reminded that their encoders should conform to the *CCSDS Telemetry Channel Coding* Blue Book (CCSDS 101.0-B-5, June 2001. Acceptable codes include:

a. Convolutional r = ½, k = 7 only;
b. Reed-Solomon 223/255 only;
c. concatenated Convolutional / Reed-Solomon and
d. **Turbo codes** with rates: ½, ? , ¼, or 1/6, block sizes: 1784, 3568, 7136, and 8920.

9. Critical Event Communications

a. Section G.4 in Appendix in the Announcement of Opportunity (AO) requires telemetry support during *Critical Events. Critical Events* are defined as: “events that could result in the loss of mission if anomalies occur” and include launch, early orbit including separation, maneuvers, all powered flight, orbit insertion, entry/descent/landing, flybys, etc.

b. An earth station is normally required during launch, early orbit and separation. It could be one of the DSN or GN Earth stations if the launch trajectory permits; however, in cases where there are gaps, another Agency's Earth station or a small portable station may be required. The project bears the responsibility and costs for acquiring and use of assets, including non-NASA assets for *Critical Event* support.